

# SAN FRANCISCO BAY CONSERVATION AND DEVELOPMENT COMMISSION

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**SUBJECT:** Climate change research needs for the San Francisco Bay coastal sector

## Staff Report

### Introduction

The San Francisco Bay (Bay) is the largest estuary on the west coast and supports a diverse natural community including open waters, tidal flats and wetlands, as well as extensive and prosperous shoreline development. However, the Bay is already stressed by impaired water quality, loss of tidal wetland habitat, and aging infrastructure. Climate change resulting from anthropogenic greenhouse gas emissions will further threaten the Bay through warming temperatures, rising sea level, increasing frequency of shoreline flooding, and other impacts of climate change.

Among these impacts, sea level rise poses an immediate threat. Shoreline developments close to the waters of the Bay are vulnerable to inundation during storm surges, and they limit the adaptive capacity of the tidal marshes to migrate landward as sea level rises. The San Francisco Bay Conservation and Development Commission (BCDC) has limited authority to address climate change, but is working closely with its partners to develop a regional research and adaptation plan for sea level rise and climate change.

Research is a necessary component of effective adaptation. It provides information for resource managers, planners, and policy makers to make informed decisions and policies. To meet these needs, it is important to perform research at various geographic scales covering different time periods. Region-wide studies are important to identify large-scale trends as well as local areas that are particularly vulnerable to climate change impacts. Furthermore, local pilot projects can test the efficacy of climate change adaptation strategies for the Bay. Monitoring of the existing Bay ecosystem can identify vulnerability and verify models of future climate change. Modeling is required to forecast the magnitude and timing of global and regional impacts of climate change and to understand the response of different, interacting parts of the Bay ecosystem.

On September 24, 2008, BCDC hosted a research forum for regional experts in policy, planning, science, and engineering. The forum focused on research for identifying vulnerability to, projecting future impacts from, and developing effective adaptation strategies for Bay area climate change. The discussion groups focused on: physical processes of the Bay and habitat



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conservation, shoreline development, and social science, legal and policy issues. The research ideas generated from the forum and through ongoing partnerships with Bay area agencies, governments, and research institutions are summarized here and in BCDC's more comprehensive report on adaptation strategies for the Bay.

### **The San Francisco Bay Ecosystem**

The existing Bay ecosystem has evolved in response to climatic forces and human management. Historic modification of the ecosystem, through filling, diking, shoreline development, and water diversions, as well as ongoing stressors such as pollution and invasive species, have resulted in the decline of many native species and increased the vulnerability of the Bay system to climate change. The region has made substantial progress in restoring the Bay ecosystem, in part by returning diked areas to tidal action and reducing pollution. However, the success of current efforts may be jeopardized by climate change impacts. Focused research is needed on (1) the vulnerability of the Bay system to climate change and (2) on adaptation measures to address the identified vulnerabilities.

**Coastal flooding and inundation.** The USGS has analyzed the effect of sea level rise on tide heights in the Bay, including the effects of tides, storm surge, and the El Nino Southern Oscillation (ENSO). However, wind-waves and river flows also affect flooding in the San Francisco Bay and Delta. Sea level rise impacts will first be seen and cause the most damage during flooding events. The USGS analysis should be further refined to include the combined effect of all factors contributing to coastal flooding, as well as refined projections of sea level rise and improved topographic and bathymetric data.

- **Bathymetric and LIDAR Data.** High-resolution shoreline topography and Bay bathymetry is needed for better modeling flood hazards and identifying changing ecosystem conditions. The USGS has created topographic and bathymetric grids of the Bay shoreline and subtidal environments. Portions of Bay topography were compiled from multiple Light Detecting and Ranging (LIDAR) datasets, sufficiently high in resolution to analyze coastal flooding (e.g. one-foot horizontal error, 15 centimeters or less vertical error). Additional LIDAR and bathymetric data collection efforts of sufficient resolution are needed for the entire Bay and shoreline. Existing data from multiple sources may be able to be integrated, or new baseline data collected for the Bay. However, because significant error can arise from integrating independent topographic data collected at different times under different methods, the efficacy and cost effectiveness of both approaches should be evaluated.
- **Shoreline Levees.** A regional inventory of the levee system is needed to more accurately model inundation due to projected sea level rise and coastal flooding. This inventory should include available information about the structural integrity of specific levees in the estuary to facilitate further analyses of shoreline vulnerabilities to sea level rise.

**Sediment Dynamics.** Adequate sediment supplies are critical for maintaining the current form of the Bay ecosystem (PWA and Faber 2004, NOAA 2007). The form, or shape, of the Bay determines tidal circulation patterns, affects the exchange of nutrients and patterns of salinity, and provides the template for Bay habitats. Bay waters supports rich subtidal habitats for many species including benthic communities and fish, and Bay tidal habitats support a diverse range of birds, fish, and other wildlife. Tidal flats form a connection between the subtidal regions of the Bay and tidal marshes, and are a primary habitat for many bird species. Tidal flats are important for monitoring the physical response of the Bay to climate change because they will

be the first and most vulnerable habitat to inundation and also supply sediment to tidal marshes to adapt to sea level rise.

Higher rates of sea level rise and declines in sediment inflow likely would result in additional loss of tidal flats, changes in the distribution of subtidal habitats, and alter tidal Bay circulation patterns. The loss of tidal flats would not only reduce this critical habitat, but also would result in erosion of existing tidal marshes, convert tidal marsh to tidal flats or shallow open water habitat and delay tidal marsh development at restoration sites like the South Bay salt ponds.

Regional sediment management (RSM) is an approach to manage sediments within the context of the entire system, including sediment sources, movement and sinks within the system and exchange with the ocean. Application of RSM to the Bay will allow BCDC and other coastal managers to (1) better understand both the impacts of individual permit decisions on the entire system (e.g. dredging and disposal), and the impacts of systemic processes such as climate change and sea level rise on permitted projects (e.g. success of wetland restoration projects); and (2) better manage Bay projects to adapt to sea level rise. In order to apply RSM, adequate data must be available on Bay sediment processes to understand how the system functions, and geomorphic or numerical models must be sufficiently accurate to predict how the system will react to changes in forcing processes, such as sea level rise or reduced inflow from the Delta. The following studies would greatly enhance our ability to implement RSM:

- **Sediment Budget.** An updated region-wide sediment budget for the Bay is necessary.
- **Monitoring Suspended Sediment Concentration (SSC).** The USGS maintains a network of stream gages along local tributaries to the Bay. SSC measurements at additional stream gages are critical for determining sediment inflow entering the Bay from local tributaries. Measurement of SSCs in the Bay as a result of wind-wave erosion and other processes is also important for monitoring sediment movement in the Bay. Furthermore, as the primary vector of pollutants entering the Bay, suspended sediment is an important parameter for monitoring water quality.
- **Sediment Coring and Tracing.** Trace element and other analyses on sediment collected in cores around the Bay are also useful for understanding the long-term trends in sediment inflow from the Delta and from local tributaries. Sediment cores can provide long-term sedimentation rates in tidal marshes in response to sea level rise (Malamud-Roam et al. 2007, Watson 2004), as well as a greater understanding of past climatic periods of flooding and drought. Sediment cores also provide empirical evidence of changing habitats under different salinity and climate regimes.
- **Shoreline Change.** Tidal marshes and tidal flats along the Bay expand or contract as a result of changes in sediment delivery from Bay tributaries and erosion of the Bay shoreline. Analysis of navigational charts ("T-sheets"), aerial photographs, and LIDAR surveys will help identify areas where shoreline erosion has occurred in the past and may occur as a result of future sea level rise. Understanding historic patterns of shoreline change will build on existing studies of tidal flats in the North and South Bay (Jaffe et al. 2007, Foxgrover et al. 2006).
- **Watershed Management Patterns.** Given the importance of watersheds in providing adequate sediment for maintaining the current form of the Bay ecosystem, additional research will be required to identify ways to coordinate RSM with watershed management practices. For example, Total Maximum Daily Load Requirements

(TMDLs) for sediment were developed in response to pollution control in tributary watersheds, but over the long term, may have negative impacts on the total volume of sediment entering the Bay.

- **Mapping of Estuary substrates.** Subtidal habitats in the Bay are greatly influenced by substrate. Existing maps of Bay substrate are outdated or incomplete, and updated maps are important for monitoring changes in the subtidal habitats in response to altered tidal circulation patterns resulting from sea level rise.

**Water Quality.** More data are needed to determine whether climate change will result in eutrophication of the Bay as a result of increases in temperature and nutrient concentrations. Other topics of interest include the potential impacts of acidification on Bay species, such as native oysters, and the exposure of legacy pollutants, such as mercury, as a result of changes in hydrodynamics and sediment dynamics.

**Plant community response to climate changes.** Research and modeling is needed to determine the habitat changes resulting from factors such as increased salinity and salinity variability. For example, increases in salinity do not always result in a conversion of freshwater marshes to brackish marshes, and of brackish marsh to saline marsh. Instead, the wetlands may become open water as plants become stressed and die. Research is needed to determine the habitat changes resulting from increased salinity and salinity variability.

- **Plant Response.** Transplant studies can be used to observe how different species adapt to increasing salinity and to determine the physical tolerances of different plants. Greenhouse studies can be used to determine how plants react to wet winters resulting in lower salinities and drier summers resulting in high salinities. Secondary impacts of vegetation shifts on other species should be studied.
- **Invasive Species.** As Bay habitats change, invasive species may become a greater concern. Little is known about how climate change may influence the potential for new and existing invasive species to become established and spread in Bay habitats. Topics of interest include inundation tolerance of invasive spartina, susceptibility of species of concern to new diseases, and the potential for changed conditions such as higher temperatures to support a new range of invasive species. Other research needs include monitoring to detect new invasive species; research on adapting to invasive species, focusing on their potential useful roles; such as the eco-engineering potential of spartina.

**Species Response to Habitat Loss.** Modeling of the loss of habitat extent and quality due to transgression and fragmentation will help identify areas that will continue to support native species of concern and those that will not. A study is needed to model a worst-case scenario of habitat loss and the implications for native species from combined impacts of climate change; for example, increasing salinity coupled with extreme heat events. In addition to further study of tidal marshes, this study should focus on the following key habitats:

- **Brackish Marshes.** Since brackish habitats have higher species diversity, understanding the potential loss of brackish habitat in Suisun Marsh will be particularly important given its overall influence on biodiversity. Additional baseline data on the distribution of plant species in Suisun Marsh and the Delta is required to better understand impacts.
- **Tidal Flats.** Tidal flats with different inundation regimes support different types of invertebrate communities and therefore vary in their value for shorebirds. The combined effect of the spread of invasive species (e.g. *Spartina alterniflora*), sea level rise, declining

sediment supply, and wind wave erosion are a threat to tidal flats. Changes in tidal flats forage value as a result of climate change impacts should be explored.

- **Subtidal Habitats.** Research is needed on impacts to subtidal habitats, such as eelgrass beds. The Subtidal Habitat Goals Project is investigating the existing stressors and impacts on subtidal habitats in the Bay and should develop research recommendations regarding the impacts of climate change.

**Bird Populations and Migration Patterns.** Baseline data on bird populations is needed particularly in the Delta. Changes in the distribution of habitats in response to physical changes in the Bay ecosystem are expected to alter the timing of bird migration. Specifically, overlap in the timing and utilization of Bay habitats by different migratory species could result in additional habitat and species loss. Modeling the pattern and timing of potential, altered migration patterns in the Bay and Delta should be performed. Additionally, research should investigate climate change impacts to nesting birds, such as heat stress and flooding of nests.

**Strategic Conservation.** Research on changes in Bay habitats will help guide the prioritization of areas for conservation and restoration. Coastal managers must accommodate the need for estuarine habitats to migrate landward as sea level rises by reserving and maintaining sufficient upland buffer areas around the Bay. Furthermore, nearly extinct habitats, such as beaches and oyster beds, should be high priority for restoration and conservation.

### **Shoreline Development**

Sea level rise and coastal flooding will impact critical infrastructure such as residential neighborhoods and commercial districts, our transportation networks of roads and rails, airports, ports and water related industries, as well as shoreline recreational areas and public access locations. Information to assess impacts to shoreline development is needed at a regional scale to define a suite of management strategies – to be applied at the local level – that balance various demands on the shoreline environment. Impacts to shoreline development can be assessed by identifying areas where coastal flooding zones (see above description) intersect with development and land use. BCDC has already conducted some of this analysis for transportation infrastructure, ports, public access locations and other shoreline development.

To facilitate further analyses that are critical for informing adaptation planning, certain regional assessments should be performed to develop the following spatial databases:

- **Upland Land Uses.** The Environmental Sensitivity Index (ESI) data, prepared by NOAA to assess coastal resources vulnerable to an oil spill, depicts shoreline types in the Bay. Gaps in the ESI dataset should be filled, including both shoreline types and upland land cover and use within a vulnerable region (i.e. approximately 0 and 10 meters above sea level).
- **Contaminated Lands.** Another important dataset will identify shoreline land with known contamination. Impacts due to inundation of contaminated lands are not known. As a result, identifying contaminated sites subject to short and long-term flooding will be critical to determining vulnerability and appropriate adaptation strategies.
- **Critical Infrastructure.** Compilation of a complete regional dataset that identifies other types of critical public infrastructure subject to sea level rise is needed. Examples of such infrastructure include, water and sewage treatment facilities, and hospitals and schools. A high priority will be mapping underground infrastructure (e.g. sewer system and oil and natural gas pipelines), which is particularly vulnerable to sea level rise.

**Pilot Adaptation Strategies for Shoreline Protection.** Once vulnerable shoreline communities are identified, pilot adaptation strategies for shoreline protection will need to be assessed. Wherever possible, these shoreline protection methods should integrate both protection from flooding and preservation of Bay habitats. Local governments need to employ innovative shoreline protection techniques in order to provide adequate flood protection while sustaining tidal wetlands on the Bay shoreline. Tidal wetlands (tidal marshes and flats) dissipate wave energy, trap sediment, and lower wave heights, all of which reduce shoreline flooding at a lower cost. A pilot project should be developed to test innovative shoreline protection techniques at a specific location on the Bay. This project would provide some of the first measurements of the dissipating effect of tidal wetlands on wave heights, a model for evaluating shoreline configurations in other locations of the Bay, and design recommendations for local governments and planners on how to use wetlands as ecologically sustainable flood protection. This effort would also be coordinated with local watershed planners to determine the connection between sediment supply and the long-term fate of the wetland (see Physical Processes).

### **Social Science, Legal and Policy Research**

Accurate assessment of vulnerabilities and the development of comprehensive adaptation strategies require an understanding of the human component of the Bay community. Vulnerability and adaptation are addressed at the very interface between humans and the environment in which they live and on which they depend (Moser 2008). Humans will be making decisions that determine whether and how both people and the environment adapt to climate change.

Research is needed to assess how social, governmental and legal systems are vulnerable to climate change, both statewide (Moser 2008, Caldwell 2008) and in the San Francisco Bay Area. This information can be used to determine changes needed to social and policy systems to improve adaptation for human systems, the Bay, and the shoreline.

**Addressing the Full Range of Adaptation.** Under most scenarios of climate change, environmental changes will be rapid and climate change effects will interact in ways that are unpredictable and lead to unexpected events (Dettinger and Culbertson 2008). Humans lack experience in assessing the limits of our capacity to adapt, which will become increasingly important under scenarios of climate change. In order to develop adaptation strategies for the Bay and shoreline, a high priority should be identifying research needs that assess the full range of human adaptive capacity. Based on interviews with social scientists and legal scholars, Dr. Susanne Moser identified a number of these research needs (Moser 2008), which apply to both the San Francisco Bay area and the nation.

- Investigate the limits of the human capacity to adapt, which will inform why and how we work upfront to mitigate impacts. This should include an assessment of human cultural, socio-economic and institutional capacity for short-term coping responses under increasing frequency of extreme events.
- Identify the mechanisms that allow humans and human systems to adapt quickly. This should include an analysis of situations where people have learned rapid adaptation and how this can be applied to Bay management.

- Investigate the “after-the-fact” impacts. An analysis of systems that occur as a consequence of a major initial impact is necessary to fully understand vulnerability and, thus, to develop comprehensive adaptation strategies.

**Social Equity and Sea Level Rise.** The effects of sea level rise will be experienced differently among shoreline residential communities, relative to a number of socio-economic and demographic factors. Low-income communities have less resources for adaptation. Further analysis of social-equity issues associated with the increased risk of flooding is required to develop effective adaptation strategies. This analysis should be robust and culturally sensitive and identify environmental justice issues, including cumulative impacts of climate change, and mechanisms for addressing environmental justice and/or social-equity issues.

**Ecosystem-Based Management: Institutional, Legal and Policy Solutions.** There are multiple government agencies with resource management mandates in the Bay and on the shoreline, including over 20 state, federal, and regional agencies, and 101 local governments within the nine Bay Area counties. For many, their legal mandates are narrow and outdated. The current species-based approach to ecosystem management makes it difficult to integrate a full range of information into planning processes to make decisions that benefit the environment. Ecosystem-based management (EBM) is an integrated approach that strives to maintain healthy, productive, and resilient ecosystems that provide the goods and services required by resident and migrant user populations, including humans (McLeod 2005). Through the use of tools such as marine spatial planning, integrated watershed management, and ocean observation and monitoring, EBM can create a pathway to effective decision-making, which alleviates uncertainty, immeasurable outcomes, and inflexibility. EBM further considers the discrepancies between ecological and political boundaries and incorporates the best scientific information available on ecosystem processes and response. It also employs adaptive management to allow managers to determine whether goals are being met and to incorporate new science and information as it becomes available. The major challenge is how to implement EBM across multiple spatial and temporal scales within the current institutional and legal framework.

The following research needs address the challenges of implementing EBM in the Bay and on the shoreline. They could be accomplished under a comprehensive regional feasibility study of an EBM approach or as individual projects:

- Conduct a detailed regional analysis of legal and institutional gaps that identifies operational barriers to and opportunities for change. The study should incorporate the best available scientific information to identify standards and mechanisms for incorporating rapid socio-economic and environmental change into decisions-making processes.
- Identify a mechanism for creating institutional flexibility using examples of successful approaches in other areas of the world, such as New Zealand, and analogs. Such analogs should include resilient ecological systems, which can provide an example for social systems, arrangements and institutions (Caldwell 2008).
- Identify mechanisms for integrating science into decision-making and decision-makers into science.
- Assess cumulative impacts on institutions as it relates to the limits of their adaptive capacity.